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Research on the Transportation Sector CO_2 Emissions and Proposals on Energy Structure Adjustment

Wei Shang[1 +], Guifen Pei[2] and Qian Gao[3]

[1,2] College of Economic, Hebei University, Baoding, Hebei071002, China

[3]Department of Economics & Management, North China Electric Power University, Baoding, Hebei 071003, China

Abstract. The data of transportation energy structure has aroused high attention of decision-makers. The paper analyses the energy consumption structure and the change tendency of transport sector in the last decade. Meanwhile, the research predicts the amount of total energy consumption and calculates the energy consumption structure in 2020 by Markov Prediction Model. By analysing different values of CO_2 default emission, we find that electric drive vehicles are likely to play a key role in the environment conservation. The CO_2 emissions from per unit of various fuels are different due to different values of CO_2 default emission factors. By using estimated transportation energy consumption and energy structure, we could calculate the CO_2 emissions of transport sector in China. Finally, in order to achieve the target of carbon intensity reduction by 40-45% based on 2005 levels by 2020, China's government should make policies to control climate warming such as increasing the energy consumption proportion of electricity by vehicles.

Keywords: transportation CO_2 emissions, Markov chain, Grey Model, carbon intensity.

1. Introduction

Since 2004, global CO_2 emissions burned by fossil fuels have accounted for 56.6% of greenhouse gas emissions. In addition, China's CO_2 emissions from fossil energy account for as high as 26.38% of the world's total and rank the first with absolute predominance [1]. In particular, the transportation sector in China has been mostly dependent on carbon-intensive sources of energy supplies and the CO_2 emissions of the transportation sector increase to 436 million tons that accounted for 7.0% to a total [2]. The increasing CO_2 emissions will continue to exert far-reaching influence on the living environment of mankind in the future, so adjusting the climate change mitigation policies about reducing CO_2 emissions in transportation sector is of great importance.

In 2009, China has announced a national target of carbon intensity (tons/GDP) reduction by 40-45% based on 2005 levels by 2020 on the Copenhagen climate change conference. Hence, reducing CO_2 emissions in the transport sector is expected to make an important contribution to achieve this target. The International Transport Forum estimated that CO_2 emissions from transportation in China had increased from 136.29 million tons (Mt) in 1994 to 524.85 Mt in 2008 [3], of which the share of national CO_2 emissions increased from 4.7% to 9%. It can be predicted that with the advancement of China's urbanization process, CO_2 emissions will be increasing constantly.

Recent years, some studies have focused on China's transportation CO_2 emissions in comparison with other countries. Lu. [4] adopted the Divisia index approach to explore the impacts of five factors on the total CO_2 emissions in Germany, Japan, South Korea and Taiwan during 1990-2002. The result showed that the growth of the road vehicle was the most important factor for the increased CO_2 emissions. Zhang. et al. [5] estimated the energy efficiencies of different transport modes in China from 1980 to 2009. Their findings

[+] Corresponding author. Tel.: + (86-0312-5073186); fax: +(86-0312-5079320).
E-mail address: (shangwei_81@163.com).

suggested that the energy efficiencies of transport energy modes in China were slightly lower than those in Jordan, Malaysia, Norway and Saudi Arabia, but higher than those in Turkey. In addition, there are also scholars concentrated on the measurement of transportation CO_2 emissions. He. et al.[6] estimated the CO_2 emissions from Chinese road transport from 1997 to 2002, his study showed that CO_2 emissions from the Chinese road transport grew from 147.77 Mt in 1997 to 229.04 Mt in 2002 with a growth rate of 9.16% per year.

Although the studies above were able to increase the reliability level of the statistical-analysis results by using a sufficient amount of data, they would not able to show the energy structure factors that determined the changes in CO_2 emissions. This paper was able to analyse the correlation among CO_2 emissions, energy consumption, and economic growth from numeric results by using the Markov switching model.

Niu. et al. [7] applied the Markov chain to predict China's energy structure by using simultaneous linear equations of transition probability matrix. They verified the feasibility of the Markov chain prediction model by an example of a region's energy consumption. Liu. et al. [8] established the Markov forecasting model of energy structure to forecast the pollutant emissions of China in 2010, and the transition probability matrix acquired by least square method.

In this paper, the Markov Prediction Model which has been proved to have the ability to forecast the energy structure change, is used to forecast the transportation energy consumption and find the limited condition to control CO_2 emissions. The remainder of the paper is organized as follows: Section 2 describes the methodology about the Markov Forecasting Model which is used in China's energy structure study. Section 3 introduces the data sources and the measurement of CO_2 emissions. Section 4 presents the contrastive forecasting results between CO_2 emissions with the limited condition and without the constraint condition. At last, key findings and recommendations are summarized in Section 5.

2. Methodologies

A Markov chain named after Andrey Markov who is a Russian mathematician. It is a random process usually characterized as memoryless: the next state depends only on the current state and on the sequence of events that preceded it. The specific kind of "memorylessness" is called the Markov property. Markov chain prediction model is a method to forecast the future state based on the same variables' present state or change tendency.

The Markov transition matrix methodology also can be helpful in the research of structure change in energy consumption area. Assume the state vector of China's energy consumption structure at the time n is S(n):

$$S(n)=\{s_c(n), s_o(n), s_g(n), s_e(n)\} \quad (1)$$

where $s_c(n)$, $s_o(n)$, $s_g(n)$, $s_e(n)$ represent the percentage of total energy consumption about coal, crude oil, natural and other energy.

We can get the one step transition probability matrix as follows:

$$\mathrm{P}(n)=\begin{bmatrix} p_{c\to c}(n) & p_{c\to o}(n) & p_{c\to g}(n) & p_{c\to e}(n) \\ p_{o\to c}(n) & p_{o\to o}(n) & p_{o\to g}(n) & p_{o\to e}(n) \\ p_{g\to c}(n) & p_{g\to o}(n) & p_{g\to g}(n) & p_{g\to e}(n) \\ p_{e\to c}(n) & p_{e\to o}(n) & p_{e\to g}(n) & p_{e\to e}(n) \end{bmatrix} \quad (2)$$

There are four steps to get the transition probability matrix:

Step1, Calculating retention probability

During the process the energy consumption structure changed from time n to time n+1, if the share of energy consumption increased, the retention probability is 1:

If $Sc(n+1)\geq Sc(n)$: $p_{c\to c}(n)=1$;

If $Sc(n+1)<Sc(n)$: $p_{c\to c}(n)=Sc(n+1)/Sc(n)$ (3)

Step2, Determine the probabilities which located in the same row with the retention probability that equaled to 1.

$p_{c\to c}(n)=1,\to\{ p_{c\to o}(n)=0; p_{c\to g}(n)=0, p_{c\to e}(n)=0\}$ (4)

Step3, Determine the nonzero probabilities which located in the same column with the retention probability less than 1.

$p_{c\to c}(n) < 1, \to \{\, p_{o\to c}(n)=0;\ p_{g\to c}(n)=0,\ p_{e\to c}(n)=0 \}$ (5)

Step4, Determine the probabilities which located in the same row with the retention probability less than 1.

$$\left.\begin{matrix} p_{c\to c}(n)<1 \\ p_{c\to o}(n)\neq 0 \\ p_{c\to g}(n)\neq 0 \\ p_{c\to e}(n)\neq 0 \end{matrix}\right\} \Rightarrow \begin{cases} p_{c\to o}(n)=\dfrac{[1-p_{c\to c}(n)]*[S_o(n+1)-S_o(n)]}{[S_o(n+1)-S_o(n)]+[S_g(n+1)-S_g(n)]+[S_e(n+1)-S_e(n)]} \\ p_{c\to o}(n)=\dfrac{[1-p_{c\to c}(n)]*[S_g(n+1)-S_g(n)]}{[S_o(n+1)-S_o(n)]+[S_g(n+1)-S_g(n)]+[S_e(n+1)-S_e(n)]} \\ p_{c\to o}(n)=\dfrac{[1-p_{c\to c}(n)]*[S_e(n+1)-S_e(n)]}{[S_o(n+1)-S_o(n)]+[S_g(n+1)-S_g(n)]+[S_e(n+1)-S_e(n)]} \end{cases} \quad (6)$$

According to the four steps above, one step transition probability matrix of energy consumption structure can be obtained. Assuming $P(1)$, $P(2)$, $P(3)$… $P(\mathrm{n})$ represent the one-step transition probability matrix, the average transition probability matrix is written as:

$P=[P(1)\,P(2)\,P(3)\cdot\ldots\cdot P(\mathrm{n})]^{1/n}$ (7)

Finally, we could obtain the forecasting results of energy consumption structure.

3. Data sources

3.1 Data selection

In the statistics yearbook [9], China's government has promulgated all kinds of energy consumption in transport sector. From the year 1994 to 2010, the proportion of diesel oil consumption rapid increased from 28.9% to 50.9% and accounted for a considerable proportion. On the contrary, the sum of coal and coke consumption continuously fell from 28.1% to 2.8% of the total. However natural gas and electricity have had a rising trend and significantly have increased since 2008. As a result, the time span of sample collection begins at 2001 and ends at 2010, beginning from the year China formally entered the World Trade Organization.

3.2 Prediction results of transportation energy structure

Calculating one step transition probability matrixes from 2001 to 2010 by Matlab 7.0 using the methodology mentioned in Section 2. The average transition probability matrix can be estimated according to eqn (7) by choosing the data of 2008-2010 considering the great difference in their matrixes structure.The average transition probability matrix indicates some information about the change of transport energy structure. The main diagonal element which close to 1 shows that the behavior to choose energy by manufacturers or consumers is relatively stable. During the period of 2008-2010, the average retention probabilities of coal, crude, gasoline, kerosene, diesel oil, fuel oil, natural gas and electricity are 91.8%, 91.5%, 95%, 100%, 98.9%, 98%, 100%, 100%. The transition probabilities transfer from coal and crude oil to natural gas and electricity are higher. At the same time, 7.35 % of coal, crude oil, gasoline, diesel oil and fuel oil transferred into natural gas, and 2.3 % of them transferred to electricity.

The prediction results of energy demands structure of 2011-2010 is based on the energy structure of 2010 and average transition probability matrix by keeping the trend of energy structure adjustment in the past. The results show that the energy demands if there is no mid and long term energy plan made by government.

3.3 Prediction results of transportation CO_2 emissions

The total transportation energy demands is forecasted by GM (1,1) based on the data during 1994-2010. Calculated it by Matlab 7.0, then the original equation of grey model is:

$$\hat{x}^{(0)}(k+1)=503.893(1-e^{-0.1023})e^{0.1023k} \quad (12)$$

The world meteorological organization provided three methods to measure CO_2 emissions of fossil fuel, here the CO_2 emissions is calculated using method 1 because the annually reported CO_2 emissions estimated by the method 1 of IPCC Guide lines is closest to the data reported by Energy Information Administration (EIA).

The predicted transportation CO_2 emissions sustained increases in the last decades, and the increasing tendency will remain in the next decades. Meanwhile, the CO_2 intensity descended smoothly from the data 0.4280 kg per Yuan in 2005 to 0.2851 kg per Yuan in 2010. However, the CO_2 intensity will decline by 33% in 2020 based on 2005, which has some distance for the CO_2 intensity to reach the target of reduction of 40%-45%.

4. Result and discussions

The planning document of energy saving and emission reduction in 12th Five-Year Plan points out that the transportation energy structure adjustment should be promoted. The Chinese government endeavors to conserve energy and reduce emissions through a series of new plan in the period of 12^{th} five-year. China enacted the "Fuel consumption evaluation method and standards for passenger vehicles", which is enforced from January 2012. It aims to decrease average fuel consumption for passenger vehicles by 15% compared with 2006. The transportation energy efficiency should be increased by optimizing energy structure, promoting technology and innovating management in the period of 12^{th} five-year. The transport department should positively advance the transfer about new energy resources for automobile such as electric vehicle, and also the natural gas vehicle is considered as a practical technology to reduce vehicle emissions.

China's government is setting about regulations to increase the shares of natural gas and new energy resources in transportation. In this paper, we assumed a scenario that the transition probability matrix adjusted by decreasing the proportion of coal consumption to 0.3%, and the natural gas consumption of the total increased to 20% and electricity increased to 15% in 2020 (Figure 1). Considering the dependence of oil products for vehicle, the energy consumption of gasoline, kerosene and diesel oil will keep the previous decreasing trend with the reducing from 77.51% to 56.51% of the total. In summary, the variation of energy structure is more rational, which will be suitable for energy saving and emissions reduction in transportation industry.

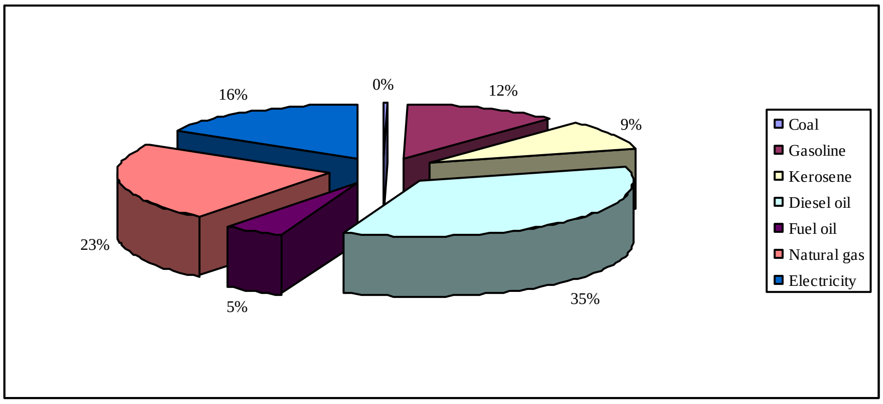

Fig. 1: The prediction results of energy demands structure in 2020 under energy policy (unit %)

Based on the predicted data above, the transportation CO_2 intensity will drop to 0.2558 kg per Yuan in 2020 from 0.4333 kg per Yuan in 2005, which achieved the scheduled target that deduced by 41%. The predicted CO_2 emissions under the energy adjustment policy decreased 188 million tons compared with the predicted data without energy adjusted policy.

5. Conclusion

The adjustment of energy structure is an effective approach to reduce CO_2 emissions. This research predicted the change rules of transportation energy consumption and calculated the CO_2 emissions by Markov Prediction Model. Considering the rapid economic growth, the total energy demands and transportation gross product were forecasted by Grey Prediction Model which was verified to have the least error. By using estimated transportation energy consumption and energy structure, we calculated the CO_2 emissions of transport sector in China. To the best of the authors' knowledge, the estimation results of road freight transportation related CO_2 emissions were reasonable and practicable [18]. The data shows that, the transportation CO_2 emissions will rapidly increase from 716.7 million tons in 2010 to 1822.1 million tons in 2020 with a growth rate of 9.8% per year without energy plan, in contrasting with the CO_2 emissions under energy policy increased to 1634.8 million tons in 2020 at the speed of 8.6% per year.

Considering the forecasting data of the CO_2 emissions in the future, we briefly discussed some important policies regarding energy structure, vehicle efficiency, road freight and new energy resources, for example: A. Based on analysing about CO_2 default emission factors, it is necessary to vigorously develop natural gas vehicle in order to improve the environment. B. Researching and applying new technology to develop the electric automobile and let it launch in the marketplace widely.

In addition, this paper discusses the importance of energy structure for reducing CO_2 emissions, but the results are restricted by energy endowment, energy market and energy technology. And the adjustment of the energy structure is not the only method to limit the fast increase of CO_2 emissions, so it will be necessary to explore other factors and measures to save energy and reduce emissions.

6. References

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